CERTIFICATION OF PHOTOVOLTAIC INVERTERS: THE INITIAL STEP TOWARD PV SYSTEM CERTIFICATION*

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ABSTRACT

There is no <u>complete</u> photovoltaic product (component or system) certification program in effect today in the United States. Photovoltaic (PV) modules and inverters are listed for safety (using standards UL1703 and UL1741, respectively), and certification for environmental qualification of PV modules is conducted [1,2]. However these do not provide critical performance information such as PV module energy rating, inverter performance characteristics, or system performance. Domestic and international standards organizations have begun writing requirements for photovoltaic system certification that are aimed primarily at small stand-alone applications. The module and balance-of-system industries often provide inconsistent or insufficient specifications and data to designers and customers to allow adequate comparison or a true prediction of performance for installed systems. This paper describes an industry consensus process to establish necessary testing protocols for certification of inverters.

INTRODUCTION

A program to certify inverter performance is a first step towards guaranteeing the quality and energy production of installed PV systems. Today's PV modules undergo extensive environmental tests and evaluations to qualify them to IEEE1262 and IEC61215/61646 [3,4]. These tests are intended to provide some assurance that the modules will maintain their performance under <u>specified</u> outdoor conditions for a reasonable period. An established certification program, such as the PowerMark Certification Program, uses procedures spelled out in the standards, along with laboratory accreditation requirements, product selection criteria, and ongoing manufacturing evaluations, to qualify photovoltaic modules [5]. While only environmental qualification tests are conducted today, expanding the program to determine and certify module performance is being considered.

The PV inverter provides the critical link between the dc PV power produced and the ac loads. A number of tests are needed to provide essential information for estimating system performance. Inverter certification tests might provide information such as maximum power tracking accuracy, efficiency variations associated with PV array and utility line variations, environmental effects, and losses that occur at night and during other protective shutdowns. Figure 1 shows variations in efficiencies found in a variety of units tested at the Photovoltaic Utility Scale Applications (PVUSA) test site and illustrates why a single efficiency value can be misleading. Similar relationships are observed for other parameters as well. Clearly, it is important for system designers to have both appropriate data, as defined by consensus test procedures, and reliable data, as provided by testing by an accredited third-party. Both are key elements of a certification program.

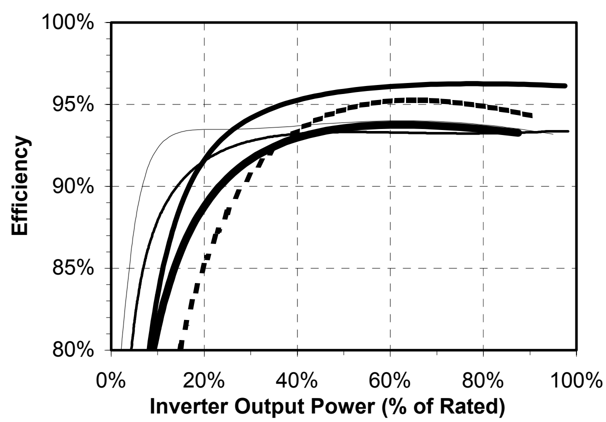

Figure 1 – Sample Inverter Efficiencies, from PVUSA

Sandia National Laboratories, the U.S. Department of Energy's lead laboratory for PV systems research and development, has been tasked to work with the industry and appropriate experts to develop a framework for a PV hardware certification program. The approach for accomplishing the certification work is tied to meaningful system goals for the nation's photovoltaic program and the photovoltaic industry. Sandia's system work is defined through five technical objectives*: (1) Reduce the life-cycle costs; (2) Improve the reliability; (3) Increase & assure the performance of fielded systems; (4) Remove barriers to the use of the technology; and (5) Support market growth for commercial U.S. photovoltaic systems.*

The certification elements tie to the National Photovoltaic Program and are a direct response to the "Photovoltaic

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Industry Roadmap", which highlighted the need for an inverter certification program. Roadmap goals include determining the key characteristics and developing test procedures that will be leading to an economical and useful certification of inverters [6]. The authors have solicited input from the photovoltaic community to determine what information, and thus which tests, are necessary and appropriate, if the inverter industry is willing to submit to these tests, and if consumers are willing to pay for them. Laboratory qualifications, accreditation, and requirements for a certifying body will be part of a hardware certification program in the future.

CAN THE PV INDUSTRY AFFORD CERTIFICATION?

A successful certification program must balance costs with the value of the information and other results obtained. Qualification and listing already places a substantial financial burden on the manufacturer. As an example, safety review and testing to UL1741 can cost $10,000 to $30,000 or more for a single inverter model with additional costs for similar models. When a new certification program is developed, the manufacturer has to decide which models to certify and when. The manufacturer has to determine how much it can invest in certification testing and how long it will take to recover those costs. For large inverters with low sales volume, such testing may be determined to be uneconomical or scheduled over many months, even years so that the investment is manageable.

Even minor design changes can lead to retesting and associated costs, thus the decision to certify a product includes a presumption that the design is fixed. This situation makes it difficult to implement design improvements in a timely manner. Depending on the tests involved, the workload of the testing lab, and other issues, several months can elapse from the decision to certify to until the certification is obtained. This delay is less of an issue in a well-developed market, but with a developing market like photovoltaics, it can seriously impact product selection, market share, and project completion.

Ultimately, the manufacturers will do what the consumers demand and the consumers will have to pay the cost. Unlike safety testing, which can be mandated by local code authorities, getting manufacturers to jump the performance certification hoop will take incentive programs and bulk purchases by large customer or groups of customers providing incentives for, or requiring, this new certification programs. Photovoltaic module qualification testing progressed primarily because of activities such as the JPL Block Program, PVUSA, and UPVG TEAM-UP. All programs tied module purchases to specific testing requirements. Companies interested in participating in those programs felt it worthwhile to submit to the tests.

ALTERNATIVES TO INVERTER CERTIFICATION

The main purpose of an inverter certification program is to provide device characterization results that any user can rely on without having to test the product themselves. In the absence of certified testing, several organizations (i.e. utilities, state organizations) have developed facilities over the years to do just that. These facilities require a great deal of capital and a long-term commitment. One disadvantage is their results may not be made public.

Lacking reliable independent performance data, some PV incentive programs are considering basing payment on actual system performance measured over a period of up to one year. This approach will address the collective arrangement of individual components and their interactions, local weather conditions, and installation issues such as shadowing, but it does not reveal the nature of the problems if they exist. Additionally, it is expensive and time-consuming and must be repeated on each system, or at least enough systems so that general system characteristics can be discerned from site and installation characteristics. It will require, at a minimum, an additional meter, procedures and personnel to read the meters, and a way to compare results and only gives "after-the-fact information for the incentive program. Some results of the metering approach may not be directly transferable to a new site or set of conditions.

WHAT IS NEEDED FOR INVERTER CERTIFICATION

Table 1 lists important tests recommended to provide certified performance data that will bolster designer and consumer confidence, and provide the information needed to better compare products and estimate the performance of an installed photovoltaic system. These tests are applicable to needs categories discussed below.

Consumer-level Comparative Information

Inverter designs used for photovoltaic systems are identical to the designs used in most other applications, with two key exceptions. First, PV inverters are typically designed to maximize the output of the PV array. The characteristic voltage-current curve of a PV array is unique, and thus special algorithms are usually incorporated to operate the array at its point of maximum power. Secondly, with the possible exception of inverters used strictly with batteries (i.e. for recreational vehicles), PV is the only application that creates such a wide range of mix-and-match opportunities between generators (PV modules) and inverters. While it is possible for the do-it-yourselfer to select an inverter for the system, it is likely that, even in our standardized, shrink-wrapped system future, the PV end user will want to compare two systems whose primary difference is the inverter. This comparative information needs to be simple, with a few numbers representing the most significant performance impacts.

The discussion of this issue parallels that of the PV module energy rating. There, the consensus seems to be that a series of four or five reference days would define sets of weather characteristics representative of certain design-days. For inverters, the standard day may be replaced with ranges of PV array type, size, and output, utility voltage, and other conditions.

Table 1. Suggested Inverter Certification Tests

Test Description	Remarks
DC Input	
MPPT Voltage Range	Key parameter for proper system design
MPPT Current Range	Can impact cable sizes
Voltage and Current Ripple (U-I Mode)	Part of MPPT effectiveness
Over-Power Response (Fold back, shut down)	Especially important when inverter rating is optimized
AC Output	
Voltage Harmonics (Stand-alone mode)	Becoming more important for a variety of loads
Power Fold back with Temperature	Can impact system performance significantly
Performance/Operational Characteristics	
Efficiency Vs. Input Power Vs. Input Voltage Vs. Output Voltage Vs. Temperature	Key parameter for optimum system performance
Weighted Average Efficiency	Important new tool for predicting performance and comparing units. Combined response to a variety of the above conditions
MPPT Accuracy Vs. Input Power Vs. Fill Factor Static vs. Dynamic	Key parameter for optimum system performance
Reference Conditions Energy Rating	Important new tool for predicting performance and comparing units. Combined MPPT and efficiency response to a variety of conditions
Array Utilization (U-I Mode)	Considers the effect of ripple and MPPT
Load Requirements (S-A Mode)	Determine a minimum load required for operation. Also characterize non-linear and low power factor loads.
Internal (Tare Losses Stand-by)	Secondary parameter for optimum system performance
Surge Capabilities (SA mode)	For motor starts and fault clearing capabilities.

Average or energy-weighted inverter efficiency may be defined relative to standard sets of conditions. A few numbers are also needed to show inverter performance with various fill-factor arrays, in poor and favorable weather, with large and small arrays. These factors may be combined in an inverter energy rating.

System Designer-level Comparative Information

A system designer needs two levels of information. The first is comparative data to evaluate prospective inverters; second is detailed design and modeling information to establish system performance and to optimize design details. From comparative-level data, the designer should be able to address the following issues:

- Effect of one more or one fewer module per string
- One size inverter for several packaged systems
- Night time tare losses
- MPPT accuracy
- Range of PV technologies (e.g. aSi - Crystalline)

Detailed Design/Modeling Information

Despite employing sophisticated PV device models, most PV System simulation programs use a single average inverter efficiency to represent all conditions or, at best, a one-size fits all efficiency versus array power model. A sophisticated model could more accurately take into account the various parameters described above with data supplied by certification testing [8].

The ability to determine array operating point (MPPT model) and resulting inverter output (efficiency model) based on weather data, array characteristics, and inverter characteristics is needed. The complete set of MPPT tests outlined in this paper is complex and time consuming. The use of a PV array simulator can reduce the test burden if results correlate with those using a PV array. Along with detailed descriptions of test procedures, a certification program will have to include detailed requirements for reference PV arrays or array simulators.

WHAT IS MISSING?

Inverters used in photovoltaic applications are already undergoing a large number of tests. Those tests are conducted on components, at the board level, as production tests, as sample tests, or as tests to ensure the operation and safety of the inverter. The tests include 1). Manufacturing processes to verify performance, set points, and functions, 2). Quality assurance for ISO9001, 3). Highly accelerated life tests, 4). UL tests for safety listing purposes, and 5). FCC for radio frequency interference.

There is no established test protocol for measuring and publishing the performance data from these tests. Conditions and procedures for measuring inverter performance have not been established, thus it is difficult to compare performance data from different manufacturers. A key step in the certification process will be to develop those standard conditions and procedures. The following discussions cover some of those key parameters.

Efficiency

Manufacturers often provide a single conversion efficiency number and may supply a table or curve of efficiency versus output power. Inverter efficiency, as shown in Figure 1, not only varies from one inverter to another, it is also strongly dependent on the voltages and power at which the system is operating. Inverter efficiency numbers quoted by manufacturers are often not comparable because they are not measured under the same conditions.

The PV system using a 2-kW array connected to a 5-kW inverter of one design may operate quite differently than when the same array is connected to a 5-kW inverter of a different design or even a 2.5-kW inverter of the same design. There are many design tradeoffs that impact efficiency. Knowing how inverter efficiency is determined will undoubtedly influence inverter design, so it is important that the procedures and conditions represent real conditions.

Maximum Power Point Tracking

Most utility-interactive inverters, and some stand-alone inverters, adjust the array operating point to maximize the array output. System design and performance predictions typically assume "perfect" maximum power point tracking (MPPT). However, because of the broad range of characteristics offered by the various types of photovoltaic modules, MPPT can be tricky to implement. Though MPPT accuracy is not often found in product literature, when questioned, most manufacturers will quote an MPPT accuracy related to the minimum dither step size used in the MPPT algorithm. If the unit never drops down to the minimum step size or if it moves to some other parameter such as maximum or minimum voltage, the algorithm may simply move up or down to operating limits. In dynamic weather conditions (windy/partly cloudy), the array IV curve may change more rapidly than the MPPT algorithm allows and lead to poor MPPT accuracy. Other aspects of the MPPT and inverter design such as ripple on the dc side also reduce MPPT accuracy.

MPPT testing is difficult to implement since the function needs to be evaluated over the same range of conditions as efficiency and must also include different array types (fill factor). Array utilization (a factor that describes the ratio of actual energy extracted versus theoretical) is often reduced because MPPT algorithms do not accurately track the maximum power point. Some of the MPPT functions in fielded installations have been found to be less than 80% effective.

Standby and Startup Losses

While efficiency and MPPT accuracy tell how the inverter is doing while operating, a significant amount of energy can be lost during standby operation. These are more critical issues for stand-alone systems where those losses may reduce the system's ability to carry loads. For utility-interactive inverters these losses directly impact system economics.

Over-power/Over-temperature Response

PV systems are typically rated at a nominal irradiance level of 1000 W/m^2. Peak irradiance values have been measured in excess of 1200 W/m^2 for extended periods in high solar irradiance areas, and over 1500 W/m^2 or 50 percent above rating conditions for short durations caused by cloud enhancement. When the input from the photovoltaic array exceeds the capacity of the inverter, it has several options. The simplest response is to cease generating power and shut down either until reset or until the overpower condition subsides. A more graceful approach would be to move off the peak power point to reduce the array output to a manageable level. Similarly, high ambient temperatures may necessitate a reduction in the power the inverter can provide. Such temperature "fold-back" can result in up to 50 percent reduction in output power capabilities. A combination of rated power and high temperature controls may also be required to limit power throughput so conductors connecting the inverter to the loads are not overloaded. Inverter over-power response can seriously impact system energy production and needs to be part of a certification test protocol.

Stand-alone Inverter Characteristics

Stand-alone inverters are typically designed to provide high surge capabilities for starting motors, and broader or skewed efficiency versus power curves to accommodate lower average power output. In addition, there is usually greater concern about standby losses, low load tare losses, and startup losses, all of which can contribute to reduced system energy production. A certification test protocol can standardize the conditions under which standby losses are measured and reported.

SUMMARY

This paper presents issues and specific areas where testing protocol for inverter certification is needed in order to predict performance and to better compare hardware during design. The testing protocol is the next step towards an inverter certification program. Once in place, the testing protocol can be used to help establish a certification program for inverters that may lead to complete PV system certification. Documentation for the inverter test protocol is in process.

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